remains an option. The relative emphasis within the architecture on vehicle based systems, and the separation of transportation management and transportation information services, are examples of choices which preserve and enhance the opportunity for private sector participation. It is forecast that several key functions will remain a public responsibility, including traffic management and emergency management services, where direct user fee based operation is impractical.

Enable Service Integration and Extend Interoperability. The strategy begins with what we have now: "islands" of basic ITS capability that are deployed in response to local needs. New standards and the continuing communications revolution will encourage service expansion and eventual linking of these ITS islands. The implementation strategy considers the minimum level of standardization required to achieve interoperability, while preserving existing investments and the potential for innovation. This balanced view emphasizes the interfaces to vehicles and other mobile elements for standardization and leaves the other regional and sub-regional interfaces to evolve towards open standards based more on local needs than top-down national priorities.

The National ITS Architecture provides a general framework that must be adapted and elaborated for use in supporting an interoperable regional transportation system design. It is recommended that regional architectures be developed as a major output of this process, which adapts the National ITS Architecture to reflect major service, technology, and interface choices which are most appropriate for the implementing region.

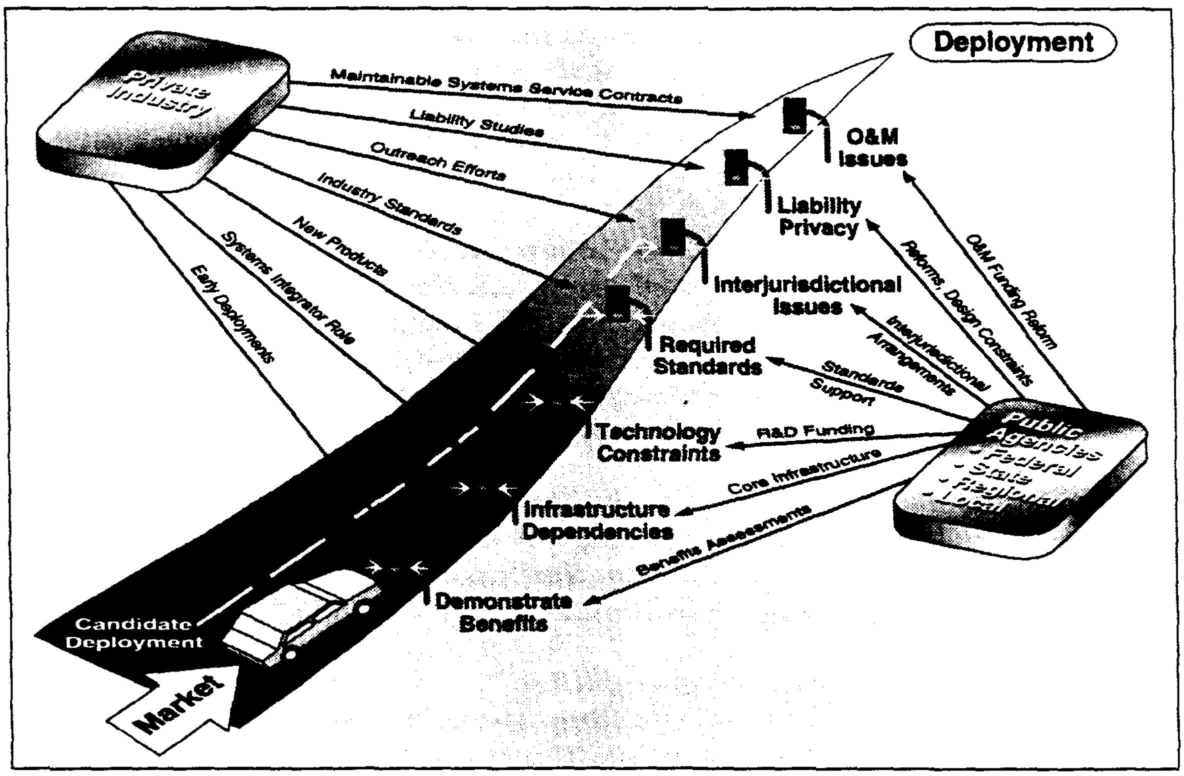
Progressive Implementation of More Advanced Services. Geographic expansion and increased integration will be paralleled by technology growth resulting in new capabilities, new products, and new features. For example, early deployment of basic toll collection capabilities enables future, efficient deployment of vehicle probe data collection, which in turn enhances advanced traveler information market packages and more advanced, area-wide traffic control strategies.

Recommended DOT Strategic Actions. The strategy culminates in a series of top-level recommendations for strategic actions that are intended to facilitate ITS deployments. These actions should lower identified barriers and otherwise enhance the prospects for efficient, interoperable ITS implementations.

> ***Facilitate National Interoperability.*** The recommendations complement the current US DOT "ITS Standards Development" activity with education programs and other forms of outreach intended to ensure active participation in, and beneficial adoption of, the standards that are developed. Legacy systems must be supported while standards adoption is encouraged in newer systems. Typically, conversion to newer, interoperable systems will occur over time in the course of normal system maintenance and upgrade. Finally, the subset of the architecture products that directly support the evolving standards and implementation guidance efforts should be maintained.

Policy and Guidance. First, the local implementor must be equipped with sufficient information to make appropriate ITS architecture choices. Education and training programs which enlist regional field representatives as local champions and continuance of the on-going federal efforts to develop, consolidate and publish ITS benefits are positive steps to this end. Each of these programs must be supported by preparation of handbook level guidance and update of existing transportation manuals, handbooks, and publications over time.

Strategic Investment. Funding recommendations are made for projects that verify and refine integration strategies (e.g., regional architecture development), field operational tests that resolve major implementation choices (e.g., the role of probes versus roadside surveillance), and research and development activities that develop the tools (e.g., Improved ITS Benefits/Impact Models) and technologies (e.g., advanced vehicle sensor and control technologies) that support ITS implementations.



Achieving Efficient ITS Deployment Through Public and Private Sector Initiatives

Navigating the Architecture Documentation

The architecture, its goals, objectives, definition, evaluation, and deployment are documented in extensive volumes. All of the information is not of value to everyone. Information is provided for the casual reader (Vision), implementors (Implementation Strategy), designers (Architecture documents), and standards organizations (Standards documents). The figure below contains a road map through the documents and helps a reader decide which document to access for more information. The casual reader may be satisfied with the Vision and Implementation Strategy documents. Detailed information is available to architects and designers in the various architecture definition documents. Specific sets of documents address architecture objectives, evaluations, and standards. In addition to the documents, information on ITS, the Architecture, and the Standards activities is available at technical forums, and on the internet.

The *Vision* contains a magazine style description of what users can expect to see in the transportation world of the future. The document contains easy to read descriptions addressing each of the major ITS stakeholders. Also presented are vignettes of life in the years 1997, 2002 and 2012.

The *Mission Definition* ties the architecture program to the national program plan. Here, the stage is set for the architecture work. The document addresses goals, objectives, user service requirements, and expected benefits. The document also contains a communications threat analysis to remind us of the pitfalls that we should avoid.

The Architecture Definition is contained in a set of 4 volumes. The *Logical Architecture* presents a functional view of the ITS user services. This perspective is divorced from likely implementations and physical interface requirements. It presents only the functions (process specifications) that are necessary to perform ITS services and the information (data flows) that need to be exchanged between these functions. The Logical Architecture document contains diagrams showing such processes and data flows between them. The document also contains a complete data dictionary.

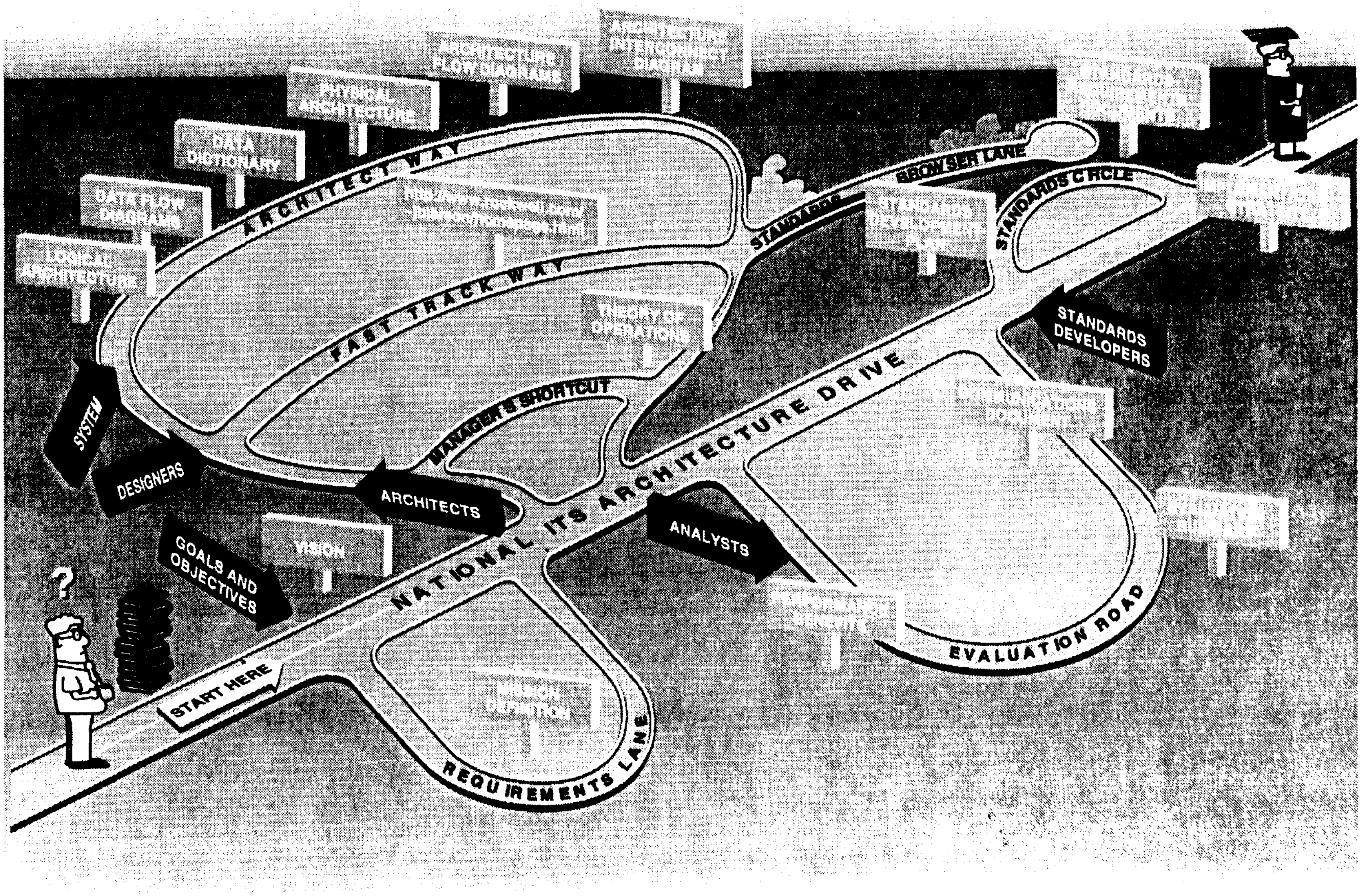
The *Physical Architecture* collects related functions together into subsystems. This document contains a collection of Architecture Flow Diagrams that show all of the data that passes between subsystems. The characteristics and constraints on the inter-subsystem data flows are also presented. The logical and physical architecture are tied together with a collection of cross-reference tables in the *Traceability Matrix*. The *Theory of Operations* provides a simple walk-through of how the architecture supports ITS implementations. This document contains easy-to-read text and diagrams that explain the operational concepts the architecture uses to implement the user services. Advantages and disadvantages of alternative operational concepts are also presented.

Several documents report the results of the numerous evaluations conducted on the architecture. Because the architecture is not something that one can directly see or touch, the evaluations are based on possible implementations. The *Communications Document* presents a thorough analysis of the communications aspects of the architecture. Analysis begins with the communications requirements resulting from analysis of the architecture data flows. Quantitative data loading requirements are proposed for a hypothetical system design whose parameters are documented in the *Evaluatory System Design*. A far reaching technology assessment is presented that covers several potential communications technology choices. These alternatives are compared with estimated ITS requirements. In particular, data loading requirements are used in a detailed simulation of one of the candidate wireless wide area communications technologies (CDPD). The document has an extensive set of appendices, each dealing with a specific communications study.

The *Risk Analysis* document assesses the risks threatening architecture deployment and suggests mitigation strategies. These strategies have been included in the overall implementation strategy for the architecture. The *Performance and Benefits Study* documents the results of a set of evaluation criteria as applied to the architecture. The results indicate that the architecture is flexible and adaptable. The document also presents an overall benefits discussion. This discussion is limited to benefits of the architecture (as opposed to benefits of ITS). ITS benefits can also be found in a number of other sources. A *Cost Analysis* document uses the same hypothetical system design used for the communication analysis, to provide a basis on which an implementor might begin to estimate the costs of deploying ITS in his jurisdiction. The evaluations are summarized in an *Evaluation Summary* document that focuses on results of the various analyses.

Support for Implementors is provided in three documents. *A Standards Development Plan* presents the steps that need to be taken to produce a collection of interface standards. The document leads a standards development organization through the architecture documents. It defines those standards that require national interoperability for nationwide deployment of ITS. Those data flows that are related to near term deployments (e.g. Intelligent Transportation Infrastructure and Commercial Vehicle Information Systems and Networks) are listed. For each deployment feature (e.g. Traffic Signal Control), either a set of existing standards activities are identified, or new standards work is recommended. In either case, architecture information should be valuable. A top level view of how to use the detailed information is presented along with a mapping from deployment features to a set of 11 standards packages. The *Standards Requirements Document* contains detailed information for each standards package. An example package is communication from the Traffic Management subsystem to the Roadside. Although NTCIP is identified as already addressing this communication link, flows exist in the architecture that are not supported by this standard.

The culmination of the architecture effort is its ultimate implementation. This is described in the *Implementation Strategy* document. The document includes sample ways in which current deployment activities can use the architecture to identify interfaces that need to be standardized. It also presents a process for rolling out ITS services. The process is part of an overall strategy that includes recommendations for future research and development, operational tests, standards activities, and training.



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Architecture Documentation Roadmap

APPENDIX G

U.S. Department of Transportation, "Intelligent Transportation Infrastructure Benefits: Expected and Experienced," *Operation Time Saver Press Kit*

U.S. Department
of Transportation

Intelligent Transportation Infrastructure Benefits: Expected and Experienced

Operation TimeSaver

January 1996

Executive Summary

The national Intelligent Transportation Systems (ITS) program started with the Intelligent Vehicle Highway Systems Act included in the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. Related activities ongoing at that time as well as new efforts have been supported through this program both technically and financially. To move ITS from research, prototyping, and pilot projects into routine usage, decision makers at the corporate, state, regional, and local levels need reliable information about the contribution that ITS products can make toward meeting the demand for safe and efficient movement of people and goods.

The experience of the US DOT has led to the definition of an Intelligent Transportation Infrastructure (ITI) consisting of traffic detection and monitoring, communications, and control systems required to support a variety of ITS products and services in metropolitan and rural areas. Whether infrastructure is deployed by the public sector, the private sector, or a combination of the two depends on the locality. The ITI provides the building blocks needed to effectively deploy and operate, as locally appropriate:

- Traffic Signal Control Systems
- Freeway Management Systems
- Transit Management Systems
- Incident Management Programs
- Electronic Fare Payment Systems
- Electronic Toll Collection Systems
- Multimodal Traveler Information Systems.

While the total picture is not clear regarding how the ITS user services enabled by the ITI relate to all transportation needs, partial results are available from early ITS projects and related deployments. Significant benefits have been recorded in areas such as accident reduction, time savings, transit customer service, roadway capacity, emission reduction, fuel consumption, and vehicle stops. Analysis and simulation based on limited tests have predicted the potential for greater benefit with more extensive deployment of more mature products.

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List of Tables and Figures

Introduction

Over three decades ago, precursors to some of the user services included in today's Intelligent Transportation Systems (ITS) umbrella began appearing in America's urban areas. Implementations have since become more flexible, more capable, and more integrated. Isolated ramp meters have developed into freeway management systems in metropolitan areas such as Los Angeles, Houston, San Antonio, and Seattle. Other cities, such as Detroit and Atlanta, are building or expanding traffic management centers that include freeway management components. Incident management programs that began as courtesy patrols and CB monitoring have incorporated new technologies and are increasingly being integrated into transportation management centers. Technologies incorporated include motorist call boxes, cellular phone call-in, loop detectors, live video and, more recently, microwave, ultrasonic, and image processing techniques. Transit fleet management has also evolved from managers with radios and clipboards to dispatch centers receiving real-time Automatic Vehicle Location (AVL) information derived from sign-post or Global Positioning System (GPS) equipment. Electronic fare payment is expanding from magnetic strip farecard use in Washington, D. C., METRO and San Francisco BART rail systems to systems that accept multi-purpose magnetic stripe cards, commercial credit cards, and non-contact electronic transaction devices. Electronic toll collection systems are being installed both in urban areas and on rural tollways.

The US DOT has defined an Intelligent Transportation Infrastructure (ITI) consisting of traffic detection and monitoring, communications, and control systems required to support a variety of ITS products and services in metropolitan and rural areas. Whether infrastructure is deployed by the public sector, the private sector, or a combination of the two depends on the locality. The ITI provides the building blocks needed to effectively deploy and operate, as locally appropriate:

- Traffic Signal Control Systems
- Freeway Management Systems
- Transit Management Systems
- Incident Management Programs
- Electronic Fare Payment Systems
- Electronic Toll Collection Systems
- Multimodal Traveler Information Systems.

ITI implementations have demonstrated benefits to address ITS national program goals in the areas of safety, productivity, efficiency, and environmental impact. Benefits are derived from a smoother traffic flow with less delay from signals, incidents, and traffic queues. Most aspects of the ITI contribute to time savings. Figure 1 summarizes the range of time savings that can be expected from ITI systems. Time savings are relative to conditions that the infrastructure elements are intended to address.

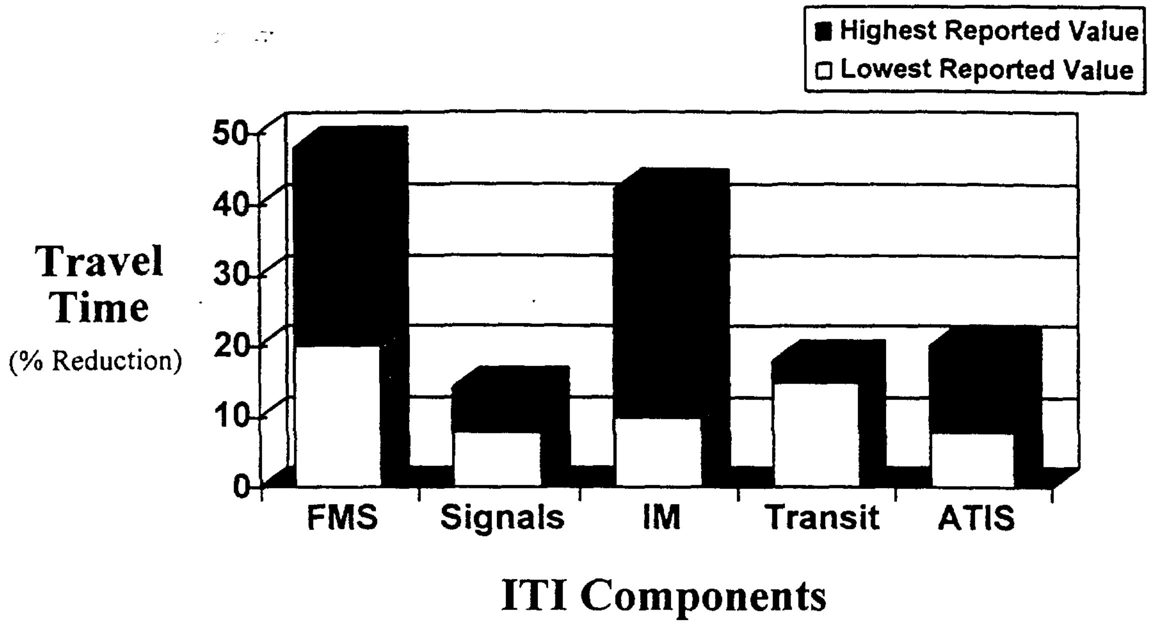

Figure 1 - Expected Time Savings from ITI System Components

While quantitative benefits and satisfactory cost estimates are not available for all components of the ITI, the systems become popular with transportation system operators once in place. The only evidence of ITI elements being disabled relate to major expansions in freeway capacity reducing requirements for ramp metering.

The rationale for installing technology solutions rather than traditional highway expansions varies with location and project type. Freeway management systems are a cost-effective way to increase throughput where additional lanes requiring expanded right of way would be too expensive or politically impossible. Several regions are using Congestion Management/Air Quality resources for Transportation Management Centers (TMCs) which remain in the planning stage, awaiting sufficient funding. Some transit operations are implementing ITS as the best way to improve passenger convenience and security. Laws requiring additional data for administration motivate local decision makers to implement other projects. In arenas where operating costs are impacted, life-cycle cost comparisons by the operating authority justify ITS; benefits to safety and the environment are additional. Some systems are deployed in jurisdictions where many residents work in technical fields and expect their governments to be early adopters of technology.

The remainder of this paper discusses the benefits of each component of the ITI on a service-by-service basis.

Freeway Management Systems

Freeway management systems have demonstrated benefits over an extended period of time and in several measurable Measures of Effectiveness (MOEs), including travel time, travel speed, freeway capacity, collision experience, fuel consumption, and emissions.

Table 1 - Summary of Freeway Management System Benefits

Travel time	Decrease 20% - 48%
Travel speed	Increase 16% - 62%
Freeway Capacity	Increase 17% - 25%
Accident rate	Decrease 15% - 50%
Fuel consumption	Decrease fuel used in congestion 41%
Emissions (Detroit study)	Decrease CO emissions 122,000 tons annually
	Decrease HC emissions 1400 tons annually
	Decrease NO_X emissions 1200 tons annually

A longitudinal study of the freeway management system including ramp metering in the Seattle, Washington, area over a six-year period[1] shows a growth in traffic of 10% to 100% along various segments of I-5 while speeds have remained steady or increased up to 48%, and accident rates have fallen consistently to a current level of 62% compared to the base period. The improvements have occurred while average metering delays at each ramp have remained at or below 3 minutes. The Minnesota DOT's Traffic Management Center, which operates freeways in the Minneapolis area, has produced the following experience[2]: Capacity is 2200 vplph compared with 1800 prior to the use of the ramp meters. Average speeds have risen from 34 mph to 46 mph. Accident rates on I-35W before management were 421 per year and dropped 308 per year. Annual accident experience on I-35W after management is 2.11 collisions/MVM compared to 3.40 before management was instituted. A survey of traffic management centers using ramp metering[3] reported similar findings. In addition to speed increases of 16% - 62% and throughput increases of 17% - 25% that were frequently used to justify the installations in a benefit/cost sense, accidents in freeway systems under freeway management were reduced between 15% and 50%. While some other freeway improvements were implemented during the study periods, the combination of geometric, vehicle, and operational procedures showed significant reductions in accident rate. The initial freeway management system in Minneapolis was developed as a demonstration project in 1968.

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[1]Henry, K., and Meyhan, O., 6 Year FLOW Evaluation, Washington State DOT, District 1, January 1989.

[2]Minnesota DOT Freeway Operations Meeting Minutes, January 1994.

[3]Robinson, J. and Piotrowicz, G., Ramp Metering Status in North America, 1995 Update, Federal Highway Administration, June 1995.

Expansions are justified by user benefits and are evaluated against other no-build options[4]. As an approximate comparison, freeway expansion costs $2 million per lane-mile while a complete implementation of an urban corridor costs $500,000 per freeway mile plus the cost of a freeway management center[5]. If the existing freeway is four lanes, installing a TMC could add about half the capacity of an additional lane at about 1/8 the cost.

As a result of reduction in delay and travel time, emissions will also be reduced. According to analysis in considering expansion of the Detroit freeway management center[6], delay under incident conditions would be reduced by about 40%, resulting annually in a reduction of 41.3 million gallons of fuel used (42%) and a reduction of carbon monoxide emissions by 122,000 tons, hydrocarbon emissions by 1400 tons, and oxides of nitrogen emissions by 1200 tons. These estimates assume the freeway management system would not change vehicle miles traveled. This analysis established the benefits of expanding the system in 1988; however, the expansion could not proceed due to budgetary constraints and competing projects. The key element in allowing this expansion was the availability of Congestion Management/Air Quality funding authorized under ISTEA[7].

Traffic Signal Systems

Transportation authorities have been installing progressively more flexible traffic signal systems since the first computerized systems were commissioned in the early 1960s. Benefits have been reported in areas including travel time, travel speed, vehicle stops, delay, fuel consumption, and emissions.

Among the earliest reported benefits, a 1966 project in Wichita Falls, Texas, reported a 16% reduction in stops, a 31% reduction in vehicle delay, an 8.5% reduction in accidents, and an increase in speeds of over 50%[8]. This analysis compared the computerized system to the single-dial system it replaced.

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[4]Carlson, G., Minnesota DOT, telephone interview, November 1995.

[5]"Comparison of Conceptual System Design and Costs: ITS Surveillance and Communication Applications: Rural vs Urban Freeway Corridors," prepared by Edwards and Kelsy for the I-95 Corridor Coalition, September 1995.

[6]Early Deployment of ATMS/ATIS for Metropolitan Detroit, prepared for Michigan DOT by Rockwell International, Dunn Engineering, and Hubbel, Roth & Clark, February 1994.

[7]Bremer, R., Michigan DOT, telephone interview, October 1995.

[8]Wilshire, R. L., "The Benefits of Computer Traffic Control," Traffic Engineering, April 1969.

Table 2 - Summary of Traffic Signal Systems Benefits

Travel time	Decrease 8% - 15%
Travel speed	Increase 14% - 22%
Vehicle stops	Decrease 0% - 35%
Delay	Decrease 17% - 37%
Fuel consumption	Decrease 6% - 12%
Emissions	Decrease CO emissions 5% - 13%
	Decrease HC emissions 4% - 10%

The Fuel Efficient Traffic Signal Management (FETSIM) and Automated Traffic Surveillance and Control (ATSAC) programs in California showed benefit/cost ratios of 58:1[9] and 9.8:1[10] respectively. ATSAC, which includes computerized signal control, reported a 13% reduction in travel time, 35% reduction in vehicle stops, 14% increase in average speed, 20% decrease in intersection delay, 12.5% decrease in fuel consumption, 10% decrease in HC, and a 10% decrease in CO.

A Texas state program called Traffic Light Synchronization (TLS) has installed 166 systems in phase I and an additional 73 in phase II. TLS analysis shows a benefit/cost ratio of 62:1[11]. The TLS was funded through Oil Overcharge funds made available through the Texas Governor's Energy Office. The City of Abilene installed a closed-loop signal system with hardware interconnect and modem link back to a shop computer. A portion of the funding for the Abilene upgrade came from a bond issue that specifically included the upgrade and the remainder came through the TLS program[12]. The system upgrade was partly to move traffic better and partly to replace an antiquated system that was causing difficulty in locating replacement parts. The portion of funding on the bond issue competed with other projects in the public works budget for priority. The City of Abilene report[13] indicates overall impacts as shown in Table 3.

The FAST-TRAC program in the Detroit area, which includes the SCATS adaptive signal control system, has seen the virtual elimination of certain types of accidents[14] as a result

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[9]Institute of Transportation Studies, University of California, "Fuel-efficient Traffic Signal Management: Three Years of Experience, 1983 - 1985," Berkeley, CA: ITS Publications: 1986.

[10]Shahrzad Amiri of LACMTA, telephone interview quoting earlier studies, April 1995.

[11]Benefits of the Texas Traffic Light Synchronization Grant Program I; Volume I, TxDOT/TTI Report #0258-1, Texas DOT, Austin, Texas, October 1992.

[12]Krieg, J., City of Abilene, telephone interview, November 1995.

[13]Evaluation Study, Buffalo Gap Road, Abilene Signal System, prepared for the City of Abilene, Texas, by Orcutt Associates, 1994.

[14]"Overview of the FAST-TRAC IVHS Program: Early Results and Future Plans," Brent Bair, James Barbaresso, and Beata Lamparski in *Towards an Intelligent Transport System, Proceedings of the First*

Table 3 - Results from Abilene Signal System Upgrade

Travel time	-13.8%
Travel speed	22.2%
Number of stops	0.3%
Delay	-37.1%
Fuel consumption	-5.5%
CO Emissions	-12.6%
HC Emissions	-9.8%
Nox Emissions	4.2%

of the installation of a traffic management system and related improvement to intersection geometrics and signal phasing. Injury accidents have decreased 6%, injuries decreased 27%, serious injuries decreased 100% during the study period, and left turn accidents decreased 89% while peak hour, peak direction speeds increased 19% and intersection delay decreased by up to 30%. During the study period, minor and property damage only accidents increased (21% in total number of accidents) and delays on minor street intersection approaches increased. FAST-TRAC is being deployed using designated federal funds.

The city of Toronto evaluated the SCOOT signal control system on two corridors and the CBD network, totaling 75 signals[15]. During an evaluation performed over a two-month period comparing the SCOOT implementation to a "best effort" fixed timing plan, the network showed decreases in travel time of 8%, in vehicle stops of 22%, in vehicle delay of 17%, in fuel consumption of 6%, in carbon monoxide emission of 5%, and in hydrocarbon emissions of 4%.

Simulation and analysis have predicted that traffic adaptive signal controls could further reduce delays and emissions compared to the currently implemented systems under certain conditions. In simulations performed for the National ITS Architecture Program using non-proprietary adaptive algorithms, delay reductions of well over 20% were observed when traffic patterns deviated from predicted levels[16].

Incident Management Programs

Incident management programs also follow an evolutionary route to full deployment. Frequently, incident management programs become part of the mission in expanding

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World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems, December 1994.

[15]Siemens Automotive, USA, "SCOOT in Toronto," Traffic Technology International, Spring 1995.

[16]Glassco, R., "Potential Benefits of Advanced Traffic Management Systems," The MITRE Corporation, ITS-L-141, November, 1995.

freeway management centers. Many of the existing incident management systems such as the Highway Helper Program in Minneapolis, the Incident Management component of the CHART Program in Maryland, and the Emergency Traffic Patrol in Illinois began as "eyes and ears" of motorists, incorporating technology such as cellular call-in, loop detectors, video monitoring, and video detectors as technology and budget constraints allowed. Incident management programs show benefits in incident clearance times and are expected to reduce fatalities.

Table 4 - Summary of Incident Management Program Benefits

Incident clearance time	Decrease 8 minutes for stalls Decrease wrecker response time 5 - 7 minutes
Travel time	Decrease 10% - 42%
Fatalities	Decrease 10% in urban areas

Incident management programs show concrete promise of reducing the 50% - 60% of traffic congestion attributable to incidents. The Institute of Transportation Engineers has estimated 10% - 42% decreases in travel time for incident management programs included in freeway management systems[17]. The Maryland CHART program is in the process of expanding to more automated monitoring with lane sensors and video cameras. CHART funding comes from a variety of sources including the state budget process and application for federal programs such as Congestion Management/Air Quality funding and Interstate Discretionary funding[18]. This program is expected to have about a 10:1[19] benefit/cost ratio according to draft analyses. The Minnesota Highway Helper Program[20] reduces the duration of a stall (the most frequent type of incident, representing 84% of service calls) by 8 minutes. Using representative numbers, annual benefit through reduced delay totals $1.4 million for a program that costs $600,000 to operate. The reduction in secondary collisions attributable to the incident management program is difficult to estimate due to the coordinated freeway management program in the area.

Using video monitoring can also aid the clearance of an incident. The City of Richardson, Texas, tied the operator of the city's towing concession into the roadway monitoring network with an investment of roughly $200. Using the information provided by the camera, the tow truck dispatcher can position appropriate equipment near the collision site prior to the request for service from the police department. This advance

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[17]Meyer, M., ed., A Toolbox for Alleviating Traffic Congestion, Institute of Transportation Engineers, Washington, D.C., 1989.

[18]Points-du-Jour, J., Maryland State Highway Administration, telephone interview, November 1995.

[19]Kuciemba, S., Maryland State Highway Administration, telephone interview, April 1995.

[20]Highway Helper Summary Report - Twin Cities Metro Area, Minnesota DOT, Report # TMC 07450-0394, July 1994.

notice reduces the response time for incident clearance by 5 - 7 minutes on average and greatly improves the ability to send equipment that will handle the active incident[21].

In addition to delay reduction benefits, incident management programs are expected to benefit safety and emission reduction efforts. An analysis of the accident statistics on several California arterials and expressways shows that secondary accidents represent an increase in accident risks of over 600%[22], without controlling for climatic or other conditions. According to draft analysis based on data from the Fatal Accident Reporting System, reduction of incident notification times on urban freeways from the current average of 5.2 minutes to 3 minutes would result in a fatality reduction of 10% annually, or a national total of 212 lives if all freeways nationwide were under such a program[23]. A reduction to 2 minutes would reduce fatalities by 308 annually. For comparison, the San Antonio TransGuide project has an incident detection goal of two minutes[24].

Multimodal Traveler Information Systems

Traffic and traveler information are popular with consumers, and systems that provide such information are producing data that anticipate system benefit when wider deployment occurs. Traveler information programs using variable message signs and highway advisory radio are funded out of highway operations budgets. Programs using kiosks and in-vehicle devices are in the pilot project stage and are funded through operational testing programs. Telephone information is making the transition from pilot to operational status. Studies have produced benefits in reducing travel delay and travel time, and predict benefits in reducing emissions and fuel consumption.

INFORM (Information for Motorists) is an integrated corridor on Long Island, New York, including information via variable message signs (VMSs) and control using ramp meters on parallel expressways and some coordination on arterials. The program stretches back to concept studies in the early 1970s and a major feasibility study performed from 1975 to 1977. The implementation progressed in phases starting with VMSs, followed by ramp meters in 1986 and 1987, and completed implementation by early 1990.

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[21] Edwards, M., Lewis Wrecker Service, telephone interview, December 1995.

[22] Intelligent Transportation Systems Impact Assessment Framework: Final Report, Volpe National Transportation Systems Center, September 1995.

[23] Evanco, W., "The Benefits of Rapid Incident Detection on Accident Fatalities," The MITRE Corporation, unpublished paper.

[24] McGowan, P., and Irwin, P., "TransGuide Transportation Guidance System: Technology in Motion," Texas DOT, November 1995.

Table 5 - Summary of Traveler Information System Benefits

Travel time	Decrease 17 minutes (20%) in incident conditions
	Decrease 8% - 20% for equipped vehicles
Delay	Decrease up to 1900 vehicle-hours per incident
Fuel consumption	Decrease 6% - 12%
Emissions	Decrease VOC 25% from affected vehicles
	Decrease HC emissions 33% from affected vehicles
	Decrease NO_X emissions 1.5% from affected vehicles

Estimates of delay savings due to motorist information[25] reach as high as 1900 vehicle-hours for a peak period incident and 300,000 vehicle-hours in incident related delay annually. Drivers will divert from 5% - 10% of the time when passive (no recommended action) messages are displayed and twice that when messages include diversion messages. Convenient alternate routes also impact diversion. Drivers will divert starting several ramps prior to the incident, with any one exit ramp carrying 3% - 4% of total approaching volume. This higher volume represents an increase in ramp usage of 40% - 70%. Accident frequency decreased slightly during the study, but data were insufficient to claim a significant trend.

Several traveler information projects are showing popularity and usage growth. The Los Angeles Smart Traveler project deployed 78 information kiosks in locations such as office lobbies and shopping plazas[26]. The number of daily accesses ranged from 20 to 100 in a 20-hour day, with the lowest volume in offices and the greatest in busy pedestrian areas. The most frequent request (83% of users) was for a freeway map. Over half of the users requested MTA bus and train information. Users, primarily upper middle class in the test area, were overwhelmingly positive in response to a survey.

An automated transit information system implemented by the Rochester-Genesee Regional Transportation Authority resulted in an increase in calling volume of 80%[27], while a system installed by New Jersey Transit reduced caller wait time from an average of 85 seconds to 27 seconds and reduced caller hang-up rate from 10% to 3% while increasing the total number of callers[28]. The Boston SmarTraveler has experienced 138%

[25]Smith, S., and Perez, C., "Evaluation of INFORM - Lessons Learned and Application to Other Systems," presented at 71st Transportation Research Board Annual Meeting, January 1992.

[26]Giuliano, G., Golob, J., and Hall, R., "Los Angeles Smart Traveler Information Kiosks," presented at the 74th Transportation Research Board Annual Meeting, January 1995.

[27]USDOT, FTA, APTS Benefits, November 1995.

[28]"NJ Transit's Customer Information Speeded Up by New System," Passenger Transport, January 24, 1994.

increase in usage from October 1994 to October 1995 to a total of 244,182 calls monthly, partly due to a partnership with a local cellular telephone service provider[29].

The Travlink test in the Minneapolis area distributed PC and videotext terminals to 315 users and made available transit route and schedule information, including schedule adherence information, as well as traffic incidents and construction information[30]. For the month of July 1995, users logged on to the system a total of 1660 times, an average of slightly more than one access per participant per week. One third of the accesses to the system requested bus schedule adherence; another 31% examined bus schedules. Additionally, three downtown kiosks offering similar information averaged a total of 71 accesses per weekday between January and July of 1995; real-time traffic data were more frequently requested than bus schedule adherence.

Surveys performed in the Seattle, Washington, and the Boston, Massachusetts, areas indicate that 30% - 40%[31] of travelers frequently adjust travel patterns based on travel information. Of those that change travel patterns, about 45% change route of travel and another 45% change time of travel; an additional 5% - 10% change travel mode.

Assuming that 30% of 96,000 daily callers change travel plans according to this breakdown, the impact of SmarTraveler in Boston on emissions has been estimated using the MOBILE5a model. On a daily basis, this adjustment of travel behavior nets an estimated reduction of 498 kg of volatile organic compounds, 25 kg of oxides of nitrogen, and 5032 kg of carbon monoxide representing reductions of 25%, 1.5%, and 33%, respectively, of these pollutants from travelers changing travel plans. While only 28,800 daily trips are expected to be affected in a metropolitan area with 2.9 million registered drivers, this represents significant reductions for participating travelers.

Simulations performed for the Architecture program using an urban scenario produced more encouraging indications of potential ATIS benefits [32]. For networks with congestion causing increases of up to a factor of 3 from free flow travel time but before saturation, equipped vehicles experience a 8% - 20% advantage in travel time. As the network becomes saturated and before congestion significantly affects travel time, the advantage of equipped vehicles is smaller. For experienced commuters, the simulation predicts an aggregate travel time benefit of 7% - 12%. The relative benefit to longer trips

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[29]SmartRoute Systems Memorandum, "SmarTraveler Update," November 6, 1995.

[30]Remer, M., Atherton, T., and Gardner, W., ITS Benefits, Evaluation and Costs: Results and Lessons from the Minnesota Guidestar Travlink Operational Test, Draft, November 1995.

[31]Air Quality Benefit Study of the SmarTraveler Advanced Traveler Information Service, Tech Environmental, Inc., July 1993.

[32]Wunderlich, K. , "Congestion and Route Guidance Benefits Assessment," The MITRE Corporation, letter ITS-L-131, October 1995.

is more significant than to shorter trips, consistent with a greater opportunity for advantageous diversion. The simulations were performed using an ATIS market penetration level of 5%. A separate simulation study predicted that pretrip information on roadway conditions could result in a delay reduction of 15% when a capacity reducing incident occurs and off-road travel options are present[33].

Studies also indicate interest in traffic information on the part of the traveler as well as willingness to react to avoid congestion and delay. In focus groups for the Atlanta Advanced Traveler Information Kiosk Project[34], 92% - 98% of participants found the current information on accidents, alternate routes, road closures, and traffic congestion to be useful and desirable. A survey in Marin County, California, showed that if regular commuters had been presented with alternate routes including travel time estimates, 69% would have diverted and would have saved an average of 17 minutes[35]. A pilot project in the Netherlands found a 40% increase in route diversions based on traffic information by the 300 vehicles equipped with FM sideband data receivers[36].

Transit Management Systems

For nearly a decade, transit properties and emergency vehicle operators have been installing and using vehicle location systems based on signpost, triangulation, LORAN, and GPS technologies[37]. A recent study[38] found 24 U. S. transit systems operating more than 10,000 vehicles under AVL supervision and another 31 in various stages of procurement. This represents a doubling of the number of deployed systems, with most new systems using a GPS-based location process. Five Canadian operators are using AVL on fleets totaling 3700 buses, including a 2300-vehicle fleet in Toronto. Coupled with computer-aided dispatching systems, vehicle location technologies are producing benefits in security, travel time, service reliability, and cost-effectiveness. Additionally,

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[33]Wunderlich, K., "Trip Planning User Service Benefits Assessment," The MITRE Corporation, letter ITS-L-131, November 1995.

[34]"Advanced Traveler Information Kiosk Project: Summary Report - Focus Groups," Catherine Ross and Associates, Inc., undated.

[35]Khattak, A., Kanafani, A., and Le Colletter, E., "Stated and Reported Route Diversion Behavior: Implications on the Benefits of ATIS," University of California - Berkeley, UCB-ITS-PRR-94-13, 1994.

[36]Broeders, W. P. B., "RDS/TMC as Traffic Management Tool and Commercial Product," Proceedings of the Second World Congress on Intelligent Transportation Systems, Yokohama, Japan, November 1995.

[37]Jones, W., ITS Technologies in Public Transit: Deployment and Benefits, USDOT ITS Joint Program Office, November 1995.

[38]Casey, R., et. al., Advanced Public Transportation Systems: The State of the Art - Update '96, USDOT FTA, January 1996.

several operators have reported incidents where AVL information assisted in resolving their disputes with employees and patrons.

Table 6 - Summary of Transit Management System Benefits

Travel time	Decrease 15% - 18%
Service reliability	Increase 12% - 23% in on-time performance
Security	Decrease incident response time to as little as one minute
Cost effectiveness	45% annual return on investment

Safety and security are major factors in decisions to install transit management systems. Situations benefitting from AVL and communication systems installed as part of transit management systems include medical emergencies as well as threats and crimes involving passengers and those observed by bus drivers. Some agencies report response times of as little as 1 to 2 minutes while others report reductions of about 40%. Agencies have reported improved cooperation with police after being able to precisely locate a bus involved in an incident and having a transit dispatcher assist in apprehending criminals using bus location information. Bus operators also report an increased sense of security with silent alarm and vehicle location capabilities[39].

AVL and dispatching systems have most directly improved schedule adherence. The Mass Transit Administration in Baltimore reported a 23% improvement in on-time performance by AVL-equipped buses. The Kansas City Area Transportation Authority improved on-time performance by 12% in the first year of operation using AVL, compared to a 7% improvement as the result of a coordinated effort between 1986 and 1989. Preliminary results from Milwaukee indicate a 28% decrease in the number of buses more than one minute behind schedule[40]. Coordination between transit systems and traffic signal systems has also demonstrated operational benefits. Allowing buses to either extend green time or shorten red time by only a few seconds reduced bus travel time on a test route in Portland[41] by 5% to 8%.

An AVL system provides a rich source of data for analyzing bus operations. Examining AVL data collected in Kansas City led to a schedule revision that reduced the 200-vehicle fleet by 7 buses while reducing scheduled travel times by up to 10%. The Kansas City Area Transportation Authority reported an annual operating expense reduction of $0.5 million based on a $1.1 million investment. Other transit systems have reported reductions in fleet size of 2% to 5% due to efficiencies of bus utilization[42]. Alternatively,

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[39]Jones, W., ITS Technologies in Public Transit: Deployment and Benefits, November 1995.

[40]Jones, W., ITS Technologies in Public Transit: Deployment and Benefits, November 1995.

[41]Kloos, W., et al., Bus Priority at Traffic Signals in Portland, ITS Annual Meeting, March 1995.

[42]Jones, W., ITS Technologies in Public Transit: Deployment and Benefits, November 1995.

the efficiency gains could be used to increase frequency by the same amount. Using AVL data for analysis purposes also reduces the need for staff to perform schedule adherence and travel time surveys. Estimates of savings range from $40,000 per survey to $1.5 million annually[43].

Electronic Toll Collection Systems (ETC)

Twelve authorities are currently using ETC, with two more scheduled to be operational by the end of 1995[44]. The decision to deploy ETC is based on reduction in operating cost to the toll authority, coupled with the benefits of emission reduction and capacity increases.

Table 7 - Summary of Electronic Toll Collection System Benefits

Operating expenses	Decrease up to 90%
Capacity	Increase 250%
Fuel consumption	Decrease 6% - 12%
Emissions	Decrease CO emissions 72% per affected mile
	Decrease HC emissions 83% per affected mile
	Decrease NO_X emissions 45% per affected mile

The Oklahoma Turnpike has been operating electronic toll collection for over four years with excellent results, including the ability to avoid staff layoffs for eliminated positions through attrition and reassignment. Statistics from the Turnpike include[45]:

Annual cost to operate automated lane - $15,800
Annual cost to operate attended lane - $176,000

Electronic toll collection can greatly improve throughput on a per-lane basis compared with manual lanes. On the Tappan Zee Bridge toll plaza, a manual lane can accommodate 350 - 400 vehicles per hour while an electronic lane peaks at 1000 vehicles per hour. By replacing 8 manual collection stations with 5 electronic lanes using the multijurisdictional E-ZPass system, and implementing a movable barrier procedure to allow an extra peak direction lane, traffic speeds have increased from a crawling 8 - 12 mph to a flowing 25 mph[46]. The New York State Thruway, which includes the Tappan Zee Bridge, benefits significantly from ETC in that expansion beyond 13 lanes for the toll

[43]USDOT, FTA, APTS Benefits, November 1995.

[44]Gallagher, M., IBTTA, telephone interview, November 1995.

[45]Oklahoma Turnpike Authority - Pike Pass Facts, undated.

[46]Zimmerman, M., New York State Thruway Authority, telephone interview, December 1995.

plaza was not an option and the toll authority had implemented tandem operations on 5 of the lanes. Roughly 110,000 electronic toll tags are now in use on the Thruway.

The Oklahoma Turnpike Authority's Pike Pass program started operation on January 1, 1991. Through June 1994, 250,000 passes had been issued, of which over 90% (226,000) were still active, accounting for 35% of revenue. Using a protocol prepared for the Northeast States for Coordinated Air Use Management (NESCAUM), the Clean Air Action Corp.[47] estimated toll booth emissions based on dynamometer tests and toll road observation at Muskogee Turnpike in Oklahoma, Asbury Plaza on the Garden State Parkway in New Jersey, and the Western Plaza on the Massachusetts Turnpike. Percent change is, of course, dependent upon frequency of toll plazas. The calculated average emissions per mile of impacted operation are shown in Table 8.

Electronic Fare Payment

Electronic fare payment is also evolving as technology improves. Rail transit systems in San Francisco and Washington, D. C. , have been using stored-value magnetic stripe fare cards purchased in the system since the 1970s. Several tests and pilot programs using newer electronic fare payment techniques are ongoing. For example, an experiment involving 2400 rail travelers using radio frequency (RF) stored-value cards has been operating in the Washington system since February of 1995. System-wide deployment of the cards is planned based on the reliability of the technology and potential improvements in convenience and security[48].

Use of electronic media for bus transit is under development. In California, tests comparing various card technologies have found RF proximity cards to be high in reliability. A test in the Marseilles, France, metropolitan area is comparing RF and infrared (IR) technologies that would allow each patron to use a card of his or her choice (credit card, debit card, monthly pass, etc.) for transportation payment, while processing a transaction in less than a second[49]. In addition to the popularity of electronic fare payment, benefits have been noted in fare collection and data collection.

The Phoenix transit operators have used electronic fare payment techniques since 1991[50]. The Arizona state legislature passed an air quality bill in the late 1980s. The county

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[47]"Proposed General Protocol for Determination of Emission Reduction Credits Created by Implementing an Electronic Pike Pass System on a Tollway," Clean Air Action Corporation study for the Northeast States for Coordinated Air Use Management, December 1993.

[48]Abramovitch, R., Washington METRO, telephone interview, November 1995.

[49]Mathieu, J., "Multiservices/Multiproviders Remote Ticketing on the Marseille Metropolitan Area," Proceedings of the Second World Congress on Intelligent Transport Systems, November 1995.

[50]Schwenk, J., "Bus Fare Payment with Credit Cards in Phoenix, Draft," The Volpe Center, November 1995.

Table 8 - Calculation of Emissions Reduction Through Use of ETC

Speed Profile (mph)	65-0-65 Toll Gate	65-30-65 Limited Pass	65 Even Full Pass
HC	1.2 g/mi	1.0 g/mi	.2 g/mi
NOx	1.1 g/mi	.9 g/mi	.6 g/mi
CO	30.6 g/mi	20.0 g/mi	8.5 g/mi
Assuming a transaction uses the average measured distance of .55 miles, each cycle produces			
HC	.66 g	.55 g	.11 g
NOx	.61	.50 g	.33 g
CO	16.8 g	11.0 g	4.68 g
The equivalent number of highway miles for a stop cycle translates to			
HC	3.3 mi	2.75 mi	.55 mi
NOx	1.01 mi	.83 mi	.55 mi
CO	1.98 mi	1.29 mi	.55 mi
% increase compared to a freeway mile			
HC	500%	400%	0%
NOx	83%	50%	0%
CO	260%	135%	0%
Based on 260 commuter days/year in summer conditions with 100% implementation, reduction in tons per year - New Jersey			
HC	0	161	596
NOx	0	126	290
CO	0	6414	12681
Reduction in tons per year - Massachusetts			
HC	0	134	206
NOx	0	57	84
CO	0	2403	3441
Assuming 100% removal of toll delay, reduction from congestion relief alone - New Jersey, in tons per year			
HC	0	52	52
NOx	0	17	17
CO	0	653	653
Reduction from congestion relief alone - Massachusetts, in tons per year			
HC	0	116	116
NOx	0	39	39
CO	0	1447	1447

Table 9 - Summary of Electronic Fare Payment System Benefits

Patron popularity	Up to 90% usage where available
Fare collection	Increase 3% - 30%
Data collection costs	Decreased $1.5 million - $5 million

encompassing Phoenix in turn passed a travel reduction ordinance that required each employer in the Phoenix area with over 100 employees to reduce single-occupancy commuting trips by 5% in 2 years. The City of Phoenix Public Transport System led development of the Bus Card Plus system to read magnetically encoded plastic passes enabling data collection to assist the commuting program , and to reduce operational problems. Employers were then billed monthly for employee transit use.

The first public use of the system was in April 1991 by employees of Valley National Bank. Currently, 190 companies participate with a total of 35,000 cards in use. Express routes report 90% of fares are paid by bus pass cards. Since employers are billed only for transit usage rather than monthly pass purchases, costs to them are decreasing by up to one third. As of May of 1995, VISA and MasterCard are also accepted. While this project has not been in operation long enough to claim firm results, patronage has been growing over the 4 months from May to September, with processing fees totaling under 7% of revenue generated, and without major problems. New Jersey Transit estimates annually cost reduction of $2.7 million in cash handling[51] while Atlanta estimates $2 million in savings[52].

While much of the literature regarding electronic fare payment discusses technical capability and patron convenience, some early indications of benefit to the transit property are discussed[53]. Reduced fare evasion has increased revenue from 3% to 30%. Estimates of reduction in data collection costs range from $1.5 million to $5 million. New York estimates the increase in ridership due to such efforts as promotional and employer sponsorship enabled by the use of electronic fare payment to be worth $49 million.

Integrated Systems

The state of the art in transportation management is the integrated transportation management center. Centers operate freeways or traffic signal systems and incorporate staff and facilities for some or all of the following: fire and rescue, surface street signal

[51]USDOT, FTA, APTS Benefits, November 1995.

[52]Jones, W., ITS Technologies in Public Transit: Deployment and Benefits, November 1995.

[53]Dinning, M., "Benefits of Smart Cards in Transit," draft, The Volpe Center, September 1995.